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June 10, 2008

Ms. Sheila Gaston
Remediation and Restoration Unit
Federal Facilities Program
Hazardous Materials and Waste Management Division
Colorado Department of Public Health and Environment
4300 Cherry Creek Drive South, B2
Denver, CO 80246-1530

Re: Evaluation of Radiological Parameters, Landfill Zone (Operable Unit 2)
Follow-up to Meeting held on April 7, 2008

Dear Ms. Gaston,

As a follow-up to our meeting with the Colorado Department of Public Health and Environment (Department) on April 7, 2008, Lowry Assumption, LLC (LAC) has performed additional analysis of data from the Operable Unit 2 Landfill Zone (OU2) radionuclide sampling as requested by Mr. Ethington (Attachment 1). This letter reports the findings of the requested analysis.

Summary of presentation made to CDPHE.
Numerous studies have been performed at OU2 to evaluate the potential for anthropogenic contamination by radionuclides including: Installation Restoration Program (IRP) Records Search (1983), IRP Phase II (1987), Remedial Investigation (RI) (1990), Supplemental RI (1995), Focused Feasibility Study (FFS) (1996), Operable Unit 5 (OU5) RI (2001), RCRA Facility Assessment (RFA) (2005), and Long-Term Monitoring for Radiological Parameters (Cabrera, 2006). All studies have concluded that the radionuclides detected in the landfill zone are naturally occurring and that no anthropogenic source of radionuclides is present in the landfill. In response to CDPHE comments on the 2006 report by Cabrera, LAC performed two additional rounds of expanded sampling and analysis for radionuclides at OU2. On April 7, 2008, LAC and an outside consultant, Dr. Donald Langmuir, met with Mr. Edgar Ethington, and representatives from EPA to discuss the findings from the additional sampling and Dr. Langmuir's evaluation of the historical data set for OU2 (see attached presentation slides). The overall purpose of the evaluation was to confirm that the data collected at the site provide an adequate understanding of subsurface conditions with respect to uranium (U), and that the proposed post-closure monitoring program, which currently includes gross alpha and gross beta analyses, will detect potential releases from the landfill.

Briefly, the April 7, 2008 presentation (Attachment 2) included information from historical investigations at the site, a summary of the analysis performed by LAC and Dr. Langmuir in 2007 and 2008, and the conclusions of that work which are summarized below.

- Elevated groundwater concentrations of uranium and gross alpha values have been detected at the northeast corner/east side of landfill throughout all investigations.
- Under the approved post-closure monitoring statistical analysis, values of gross alpha, which is a broad indicator for uranium, do not occur at "statistically significant" higher values in downgradient wells.
- Uranium isotope ratios demonstrate that the dissolved uranium detected in groundwater at OU2 is derived from a naturally occurring source or sources.
- Uranium concentrations in the alluvial aquifer elsewhere in the Denver Basin are often elevated, averaging 24 micrograms per liter (µg/L), and often exceed 70-100 µg/L.
- Groundwater flow from the location of a reported "radioactive material area" in OU2, is to the north - in the wrong direction, to be the source of elevated dissolved uranium concentrations detected in the alluvial aquifer at the east-northeast corner of the landfill.
- Possible explanations for the elevated U concentrations found in some groundwaters in the alluvial aquifer under OU 2, include:
  - Natural sources, (see attached presentation and summary of Dr. Langmuir's report below describing leaching of U from uraniferous materials exposed in a buried paleochannel in the underlying Denver Formation and contribution from iron oxides);
  - Concentration of the U in groundwater recharge by evapotranspiration;
  - Leaching of U from phosphate fertilizers applied at the Mira Vista Golf Course.
- Recommendations for post-closure monitoring
  - Continue post-closure monitoring of gross alpha and gross beta as a means to detect any changes in U concentrations that would be indicative of a potential release.

At the April 7th meeting, there was agreement from the Department that the detections of uranium at the landfill reflect a naturally occurring source – not an anthropogenic or processed source.

The outstanding questions posed by the Department were:

1. *Where is the documentation for the statistical analysis of gross alpha?*

2. *Was it possible that waste materials, disposed in the landfill, were responsible for the elevated uranium concentrations?*

Responses:

1. Where is the documentation for the statistical analysis of gross alpha?

LAC has performed seven quarters of post-closure monitoring at the landfill in accordance with the approved Final Phase 2 Corrective Action Plan for the Operable Unit 2 Landfill Closure (Phase 2 CAP), (LAC, November 2003). The monitoring program includes analysis for gross alpha and gross beta as a broad screen for changes in radionuclide concentrations, and it includes a process for statistical evaluation of the data designed to detect a possible release from waste materials. Reports for the first six of seven quarterly monitoring events have been submitted to Department and are listed below.

- 4th Quarter 2006 (submitted 1/17/07 and comment responses submitted 05/15/07)
- 1st Quarter 2007 (submitted 4/18/07)
- 2nd Quarter 2007(submitted 6/27/07)
- 3rd Quarter 2007 (submitted 11/14/07)
- 4th Quarter 2007 (submitted 1/21/08)
- 1st Quarter 2008(submitted 4/18/07)
- 2nd Quarter 2008 (expected submittal June 2008)

In accordance with the approved Phase 2 CAP for OU2, statistical analyses have been performed with data from the 2nd, 4th, and 6th quarters (1st quarter 2007, 3rd quarter 2007, and 1st quarter 2008) as the full statistical dataset is being populated.

The most recent report (1st Quarter 2008) describes that the gross alpha concentration in the downgradient wells are not statistically higher than the upgradient concentrations (represented by the upper prediction limit (UPL)). The report states:

> "In accordance with the work plan, two radionuclides were tested (gross alpha and gross beta). Both parameters were detected in 100% of the upgradient and downgradient samples. Gross alpha was determined to be normally distributed and gross beta log-normally distributed; the parametric method was used as described above. The October 2007 gross alpha concentration from downgradient monitoring well LFPOC13 (reported as 90 +/- 15 pCi/L) slightly exceeded the calculated UPL of 88 pCi/L; however, the January 2008 gross alpha result (65 +/- 11) was again below the UPL as were all results prior to the October 2007 event."

LFPOC13 is not considered to be a downgradient well, as discussed in the April 7 presentation to the Department and in the attached report (Langmuir, 2008). The well, located on the east side of Westerly Creek on the golf course property, was installed when it was thought that there may have been disposal in a triangular shaped parcel east of the creek and just south of the well; however, information gained during construction of the cap and from more extensive aerial photo review indicate that there was no disposal in that area. Well LFPOC13 is not downgradient of the landfill zone, rather it is cross-gradient between the golf course and the landfill zone. Nitrate data (see Langmuir, 2008) demonstrate that well LFPOC13 is more likely influenced by upgradient groundwater and fertilizers used on the golf course rather than by landfill disposal.

2. Was it possible that waste materials disposed in the landfill, were responsible for the elevated uranium concentrations?

   Dr. Langmuir performed additional evaluation of the site data following the April 7th meeting to provide a specific response to the Department's question, and his detailed findings are presented in the attached report. In summary, the data demonstrate that waste uranium ore at the landfill, if present, is **not** responsible for the elevated concentrations detected at the landfill for the following reasons:

   - Groundwaters in the Alluvium are undersaturated by 300 times or more (>$10^{2.5}$ times) with respect to any possible uranium minerals that could occur in an ore or waste deposit, indicating that those minerals are not present in the Alluvium, and thus no ore deposit is present. **The same mineral saturation calculations also indicate that no large quantity of waste uranium ore has been buried at the site.**
   - Uranium concentrations in alluvial groundwaters are buffered/maintained at relatively constant and sometimes elevated values because of adsorption/desorption of the uranium by ferric iron oxides in the Alluvium.
   - The likely source of elevated uranium concentrations in alluvial groundwaters is from leaching of uraniferous sediments in the underlying Denver Formation which contains lignite and coal seams. These sediments are exposed along a paleochannel eroded into the Denver Formation on the east side of OU2. Data showing the existence of such lignite deposits in the Denver Formation are presented in Dr. Langmuir's report. In addition, Kirkham and Ladwig (1979) show the lignite unit cropping out in the vicinity of the landfill zone (Figure 1), and site specific occurrences of coal/lignite/tuff identified in the upper Denver Formation have been reported in Remedial Investigation borings at Lowry just east of the landfill (SAIC, 1990).
   - East of Westerly Creek, another possible source of uranium is phosphate fertilizers applied at the Mira Vista Golf Course, which have subsequently been leached by rainfall and irrigation. Literature sources in which very high uranium concentrations have been detected in porewaters from fertilized areas were presented to the Department in the April 7th meeting, supported by similar results from the South Platte Valley and the Denver

area. In addition, elevated groundwater nitrate values (1.4-3.0 milligrams per liter [mg/L] as N) in well LFPOC13, a high uranium well (130 μg/L) which is under the golf course, could derive from the leaching of nitrogen fertilizer applied at the golf course. This would be consistent with the leaching of uranium from phosphate fertilizers at the golf course

Summary:

LAC's assessment of historical radionuclide data and the additional data collected in 2007 was presented to the Department on April 7, 2008. The results of further evaluation requested by the Department in that meeting are provided in this letter and its attachments. The assessment documents that the only radionuclide with elevated concentrations within landfill zone groundwaters is uranium and its surrogate, gross alpha. Statistical evaluation of gross alpha performed as part of the Department-approved post-closure monitoring program for OU2, documents that gross alpha is not statistically elevated in downgradient wells at the landfill and in response to the first question from CDPHE in the meeting, the requested references for this analysis have been provided in this letter. In response to the second question posed by CDPHE, regarding the possibility of uranium ore having been disposed in the landfill, calculations by Dr. Langmuir show that the groundwater is undersaturated with respect to uranium minerals, precluding the possibility that waste uranium ore buried in the landfill could be responsible for elevated uranium concentrations in the groundwater. He further describes that lignite/coal deposits in the upper Denver Formation, documented in the literature and by site observations, and intersected by the paleochannel beneath the landfill are likely the chief source of elevated uranium concentrations in the groundwater. A second potential uranium source east of Westerly Creek is leaching of phosphate fertilizers applied at the Mira Vista Golf Course.

LAC has completed the extended data collection and analysis of radionuclides in the landfill zone. The data has been presented to CDPHE and the outstanding questions asked by the Department answered in this letter. LAC requests concurrence from the Department that this issue has been satisfactorily addressed. LAC will continue to monitor gross alpha and gross beta and perform detection monitoring as set forth in the Department approved post-closure monitoring program.

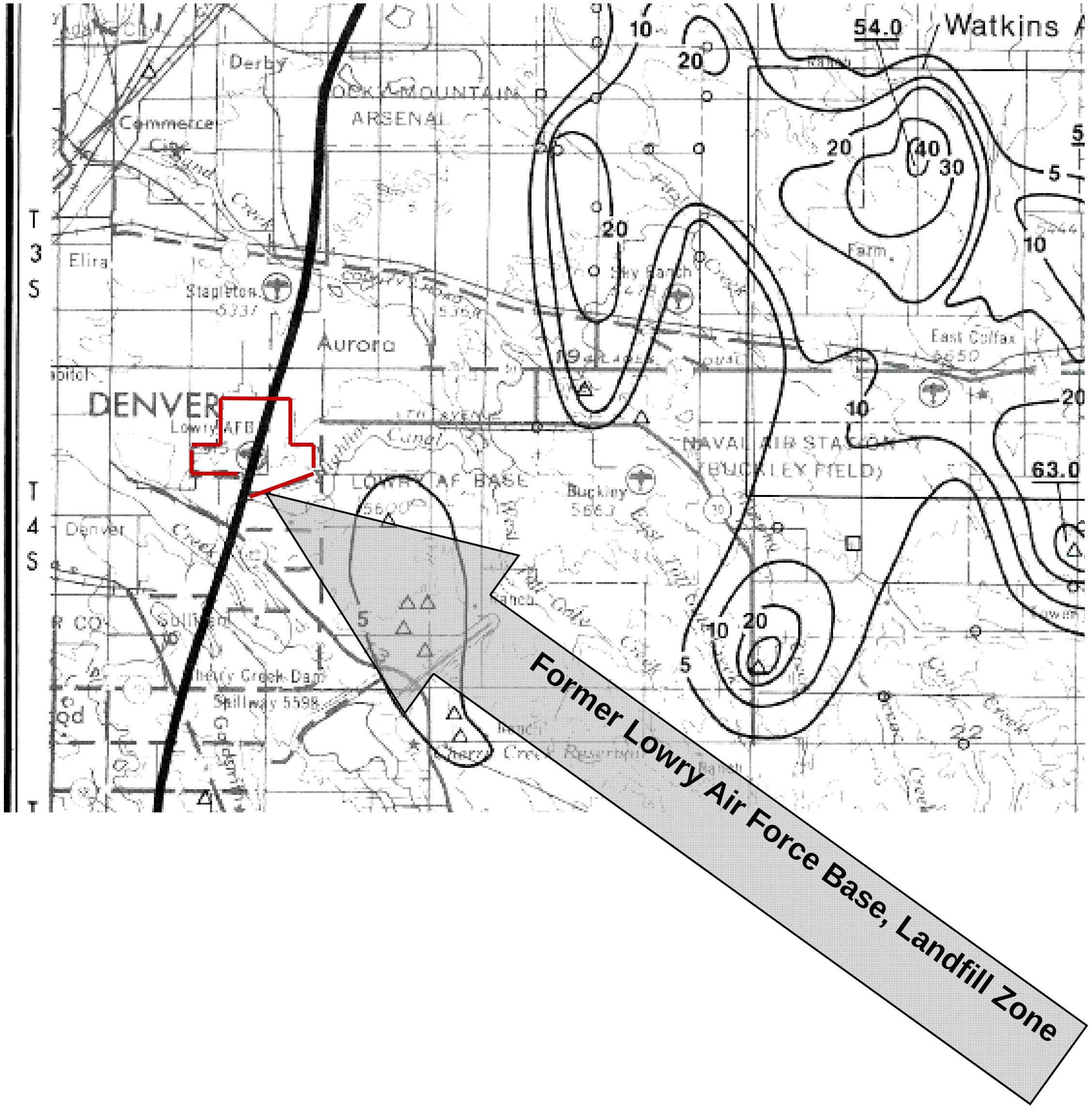
Sincerely,

Joseph Aiken
Program Manager

Lowry Assumption, L.L.C.

Distribution:
Edgar Ethington - CDPHE
Karen Hancock - Aurora
David Erickson - CCOD
Stanley Pehl - AFCEE (2)
Paul Carroll - AFRPA/DC-Reese
Pat Smith - EPA Region 8
Monty Force - LRA
Ann Wei - IRG
Elizabeth Sopher - LAC (2)
Lowry Project File

FIGURE



EXPLANATION

Contour Line showing total thickness of all known lignite beds in the Denver Formation; contour lines at 5, 10, 20, 30, 40, and 50 feet; in some areas certain lines are omitted for clarity

50.0 Maximum total lignite bed thickness in each area

Outcrop or Subcrop Line of lignite-bearing rock in the Denver Formation; dashed where approximately located

Data points:
- ○ Coal exploration drill hole
- • Oil or gas drill hole
- △ Water well
- □ Abandoned lignite mine

From: Figure 2, Plate 2 of 5, Total Lignite Bed Thickness in the Denver Formation. Kirkham, R. M. and L.R. Ladwig, 1979. Coal Resources in the Denver and Cheyenne Basins, Colorado. Resource Series 5, USGS, Denver, CO.

Figure 1
Location of Lignite Subcrop
Denver Formation
Lowry Assumption, LLC June 2008

Attachment 1
Source of Uranium in Groundwaters Under Operable Unit 2, Landfill Zone, Former Lowry Air Force Base

Dr. Donald Langmuir
Hydrochem Systems Corporation

June 3, 2008

SOURCE OF URANIUM IN GROUNDWATERS UNDER OPERABLE UNIT 2, LANDFILL ZONE, FORMER LOWRY AIR FORCE BASE, DENVER, CO

Submitted by:
Donald Langmuir, PhD
President
Hydrochem Systems Corp.,
Silverthorne, CO

Submitted to:
Lowry Assumption, LLC,
Littleton, CO

June 3, 2008

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1. Executive Summary

- There is no natural uranium ore deposit or waste uranium ore in the Piney Creek Alluvium within Operable Unit 2 (OU 2) at the former Lowry Air Force Base Landfill. This conclusion is based on the following:
    - Groundwaters in the Alluvium, which contain 20-150 micrograms per liter (µg/L) Uranium (U), are nevertheless undersaturated by 300 times or more (>$10^{2.5}$ times) with respect to any possible uranium minerals that could occur in an ore deposit. This indicates that such an ore deposit is not present in the Alluvium, and that no large quantity of waste uranium ore was disposed of at the site.
    - The Alluvium is less than 11,000 years old. No uranium ore deposits found in the Denver Basin are younger than 33 million years old.
    - Known sandstone-type uranium deposits (such as this would be) form under conditions that do not exist in the Piney Creek Alluvium. These are:
        - There must be a nearby (usually younger and overlying) deposit that contains elevated uranium concentrations that can be leached, providing a source of U for the deposit.
        - The prospective host formation must contain reducing materials such as lignite and coal (or hydrogen sulfide gas) to precipitate the uranium to form the ore deposit. Such reductants are absent in the Piney Creek in which conditions are oxidizing.

  The likely source of elevated uranium concentrations in alluvial groundwaters is from leaching of uraniferous sediments in the underlying Denver Formation which contains lignite and coal. These sediments are exposed along a paleochannel eroded into the Denver Formation on the east side of OU 2. East of Westerly Creek, another possible source of uranium is phosphate fertilizers applied at the Mira Vista Golf Course, which have subsequently been leached by rainfall and irrigation waters.

- Uranium concentrations in alluvial groundwaters are locally buffered/maintained at relatively constant and sometimes elevated values because of adsorption/desorption of the uranium by ferric iron oxides in the sediment.

2. Geology of the Site

At the site, the surface Piney Creek Alluvium, which is of Holocene age (<11,000 yrs)(Cabrera, 2006), is the chief local groundwater aquifer and thus of most environmental concern. The Alluvium overlies the Denver Formation (of Late Cretaceous-early Paleocene age). The Piney

Creek, which also includes loess deposits, is comprised of sand and silty-sand with interbedded layers or lenses of sandy clays, silty clays, and sandy gravels.

The Alluvium overlies an erosional bedrock surface of the Denver Formation which is made up of claystones, siltstones, fine-grained sandstones, and locally lignite and low-grade coal seams. The Denver Formation is generally comprised of much less permeable sediments than the Alluvial Aquifer. The bedrock surface of the Denver Formation is locally weathered and varies from granular to more lithified material, which may be fractured and jointed to depths of 5 feet (ft) or less (PHA, 1996). A short distance northeast of OU 2 the upper 300-500 ft of the Denver formation contains commercial coal deposits (now depleted), and/or carbonaceous shale and lignite (Kirkham and Ladwig, 1979; PHA, 1996; Nichols, 1999). Beds of more permeable sandstone and lignite within the Denver Formation comprise what is termed the Denver Aquifer. OU 2 is located along the western edge of a portion of the Denver Formation that contains lignite beds (Kirkham and Ladwig, 1979). The Denver Aquifer is locally confined above and below by relatively impermeable shales and claystones (PHA, 1996), and thus may contain reducing (low Eh) groundwaters.

Erosion of the buried surface of the Denver Formation prior to deposition of the Piney Creek Alluvium created a paleochannel about 10-20 ft deep in the top of the Denver Formation. The axis of this buried channel trends from beneath the southeast corner of the site (under Westerly Creek) towards the northwest and north-northwest where it exits the site (Fig. 1). Coarser sandy and gravelly Alluvium tends to fill such buried channels, giving them higher hydraulic conductivities and groundwater flow rates than found in adjacent alluvial materials (PHA, 1996). Erosion of the buried channel may have exposed lignitic (carbonaceous) materials near the top of the Denver Formation to alluvial groundwaters.

3. Occurrence of Uranium Ore Deposits

A generalized geologic map of sediments in the Denver Basin and a cross-section through those sediments from east to west is shown in Fig. 2 below. The Alluvium, which lays directly on the Denver formation at OU 2, is not shown in the figure, but increases in thickness towards the South Platte River which flows north and northwest of the site. At OU 2, the Alluvium ranges from 10-60 ft thick, and is generally thickest in the eastern part of the landfill. The Dawson Formation is absent at the OU 2 site. The age of the sediments in the Basin at OU 2 ranges from <11,000 yrs old (the Holocene aged Piney Creek Alluvium) to the Late Cretaceous Fox Hills and Laramie Formations (>66 million years old).

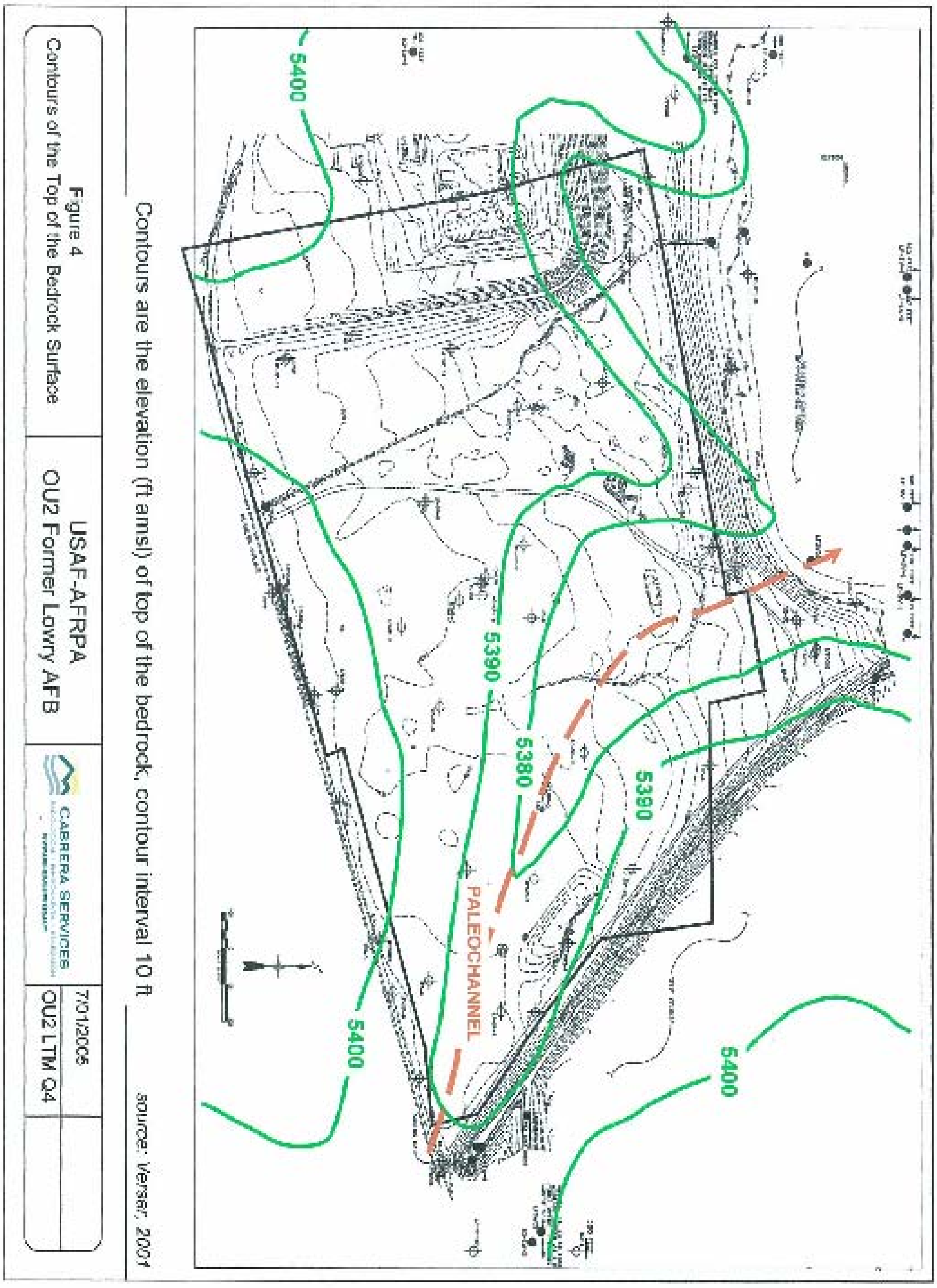

Figure 1. Elevation (ft) above mean sea level of top of buried Denver Formation. From Cabrera (2006). The inferred axis (bottom) of the buried paleochannel is shown as a brown dashed line.

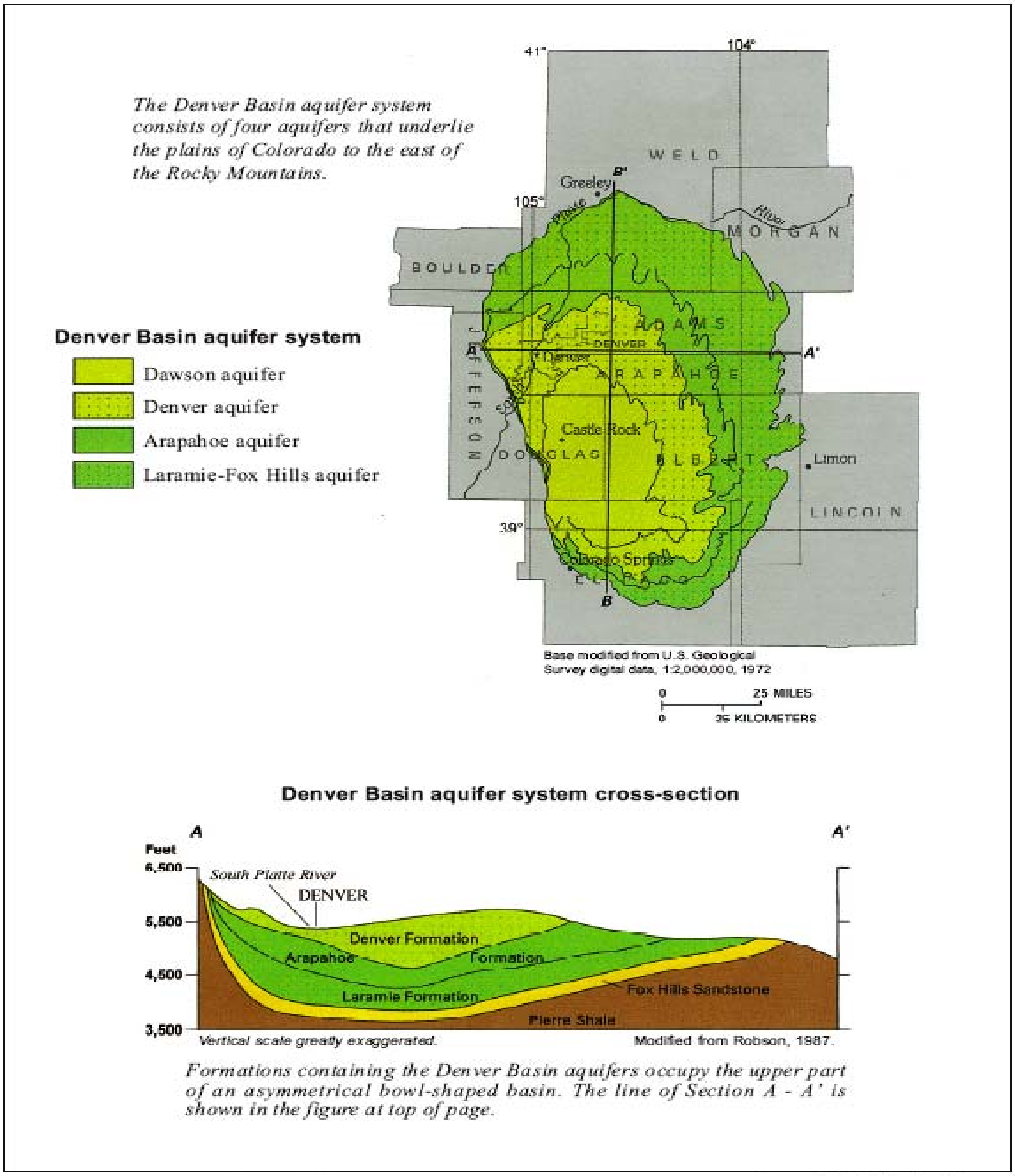

Figure 12. Denver Basin Aquifers.

Source: U.S. Geological Survey, Ground Water Atlas of the United States.

Fig. 2. A generalized geologic map of sediments in the Denver Basin and a cross-section through those sediments from east to west. From USGS (2005)

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All mined uranium ore in the Denver Basin is of Eocene age or older (>33 million years) (Cabrera, 2006). Economic uranium deposits (average U_3O_8 grade 0.1%) occur in the Fox Hills Formation near Greeley in the Centennial Project (Voss and Gorski, 2007).

Economic uranium deposits that occur in sediments such as those of the Fox Hills Formation are described as 'sandstone-type' deposits. Such deposits are also associated with the Morrison Formation near Morrison, Colorado and in western Colorado and Utah (cf. Phoenix, 1958)).

Sandstone-type uranium deposits are formed under unique conditions (cf. Adler, 1963). First, there must be a geologic formation which is a source of elevated uranium concentrations. Second, there must be a zone in the sediment in which the uranium is being transported in groundwater as oxidized and soluble uranyl (U(VI)) species, where the groundwater comes in contact with reducing materials or gases in the sediment (lignite, coal, petroleum, hydrogen sulfide, etc) to locally convert the dissolved U(VI) to insoluble U(IV) minerals forming the ore deposit. For these reasons, sandstone-type uranium deposits are found in older, buried sediments, not in recent alluvial surface materials.

The source of uranium for a sandstone-type U deposit may be a permeable volcanic tuff. For example, the tuffaceous White River Formation overlies a uranium deposit in the Fox Hills Formation in the vicinity of the Centennial Project in Weld County. Similarly, sandstone-type U deposits in the Oakville Formation of Texas probably obtained their uranium from leaching of the overlying Catahoula Tuff (cf. Langmuir and Chatham, 1980). Granites are also relatively high in uranium, so that arkosic sandstones, which are formed by the weathering of granite, may also be a source of dissolved U. This is the likely uranium source for sandstone-type uranium deposits at the Wasatch site in the Powder River Basin of Wyoming (Langmuir and Chatham, 1980).

The Piney Creek Alluvium is a very young surface deposit which has no access to overlying uranium-rich source materials, and is largely lacking of organic matter or other reducing materials that could reduce and concentrate the uranium in its sediments.

The Denver Formation is not known to contain economic deposits of uranium minerals. There are no sediments overlying the Denver Formation that contain significant amounts of uranium source materials. However, the Denver Formation does contain appreciable organic matter in lignite and coal as shown in Fig. 3 (see also Kirkham and Ladwig, 1979). Before the Denver Formation was exposed to surface erosion and oxidation, such reducing materials would have concentrated any available uranium from the groundwater, particularly where formation sands were confined below less permeable clay beds. Such traces of reduced uranium minerals could now be being leached by oxygen-rich alluvial groundwaters, particularly along the sides of the buried erosion channel in the top of the Denver Formation under OU 2 which is shown in Fig. 1.

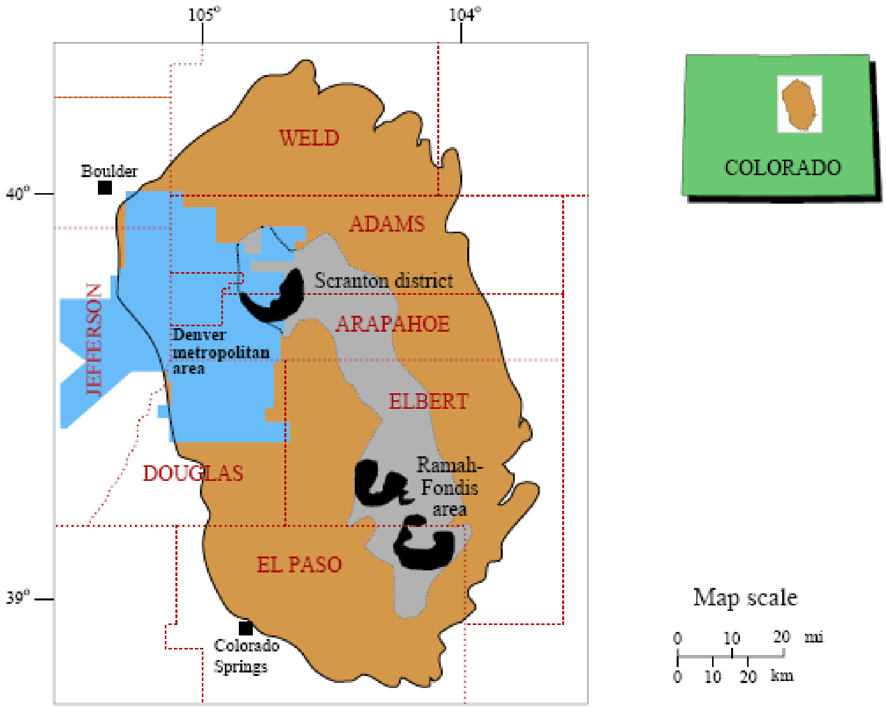


Figure SD-2. Index map of the Denver Basin (orange), Colorado, showing counties, the Denver metropolitan area, other major cities, area of occurrence of potentially strippable lignite (defined as beds less than 200 ft in depth, shown in gray on map) in the Denver Formation, and coalfields where mines were active in the past (black). The basin margin is drawn at the base of the coal-bearing part of the Upper Cretaceous Laramie Formation. Modified from Landis (1959) and Kirkham and Ladwig (1979, 1980).

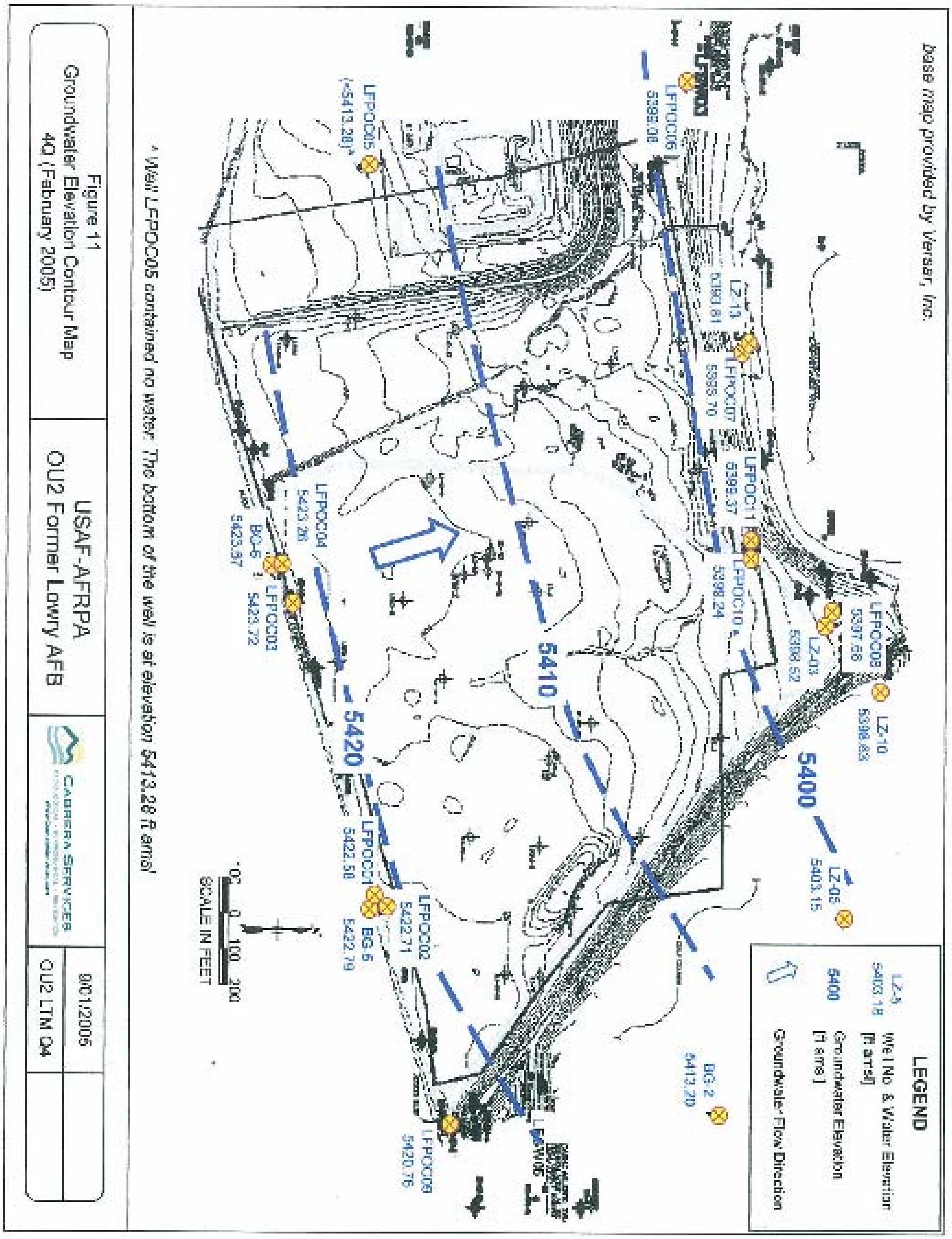
Fig. 3. Occurrence of strippable lignite (grey) and coalfields (black) actively mined in the past in the Denver Basin. These deposits are largely in the Denver Formation. From Nichols (1999)

Hydrogeology of the Alluvium

The elevation of the groundwater table in the Alluvium (Fig. 4) trends smoothly from 5420 ft above mean sea level (amsl) along the southern boundary of the site to 5400 ft amsl near the northern site boundary, north of which it drops rapidly off the edge of the site to values near 5394 ft amsl. Comparison of the elevation of the land surface and of the underlying water table shows that the depth to the water table ranges from 12-14 ft along the south side of OU 2, to 10-18 ft E-W across the middle of the site, to 12-14 ft along the northern boundary of OU 2.

Comparison of the water table elevation map for the Alluvium (Fig 3) with the map of the elevation of the underlying Denver Formation (Fig. 1) indicates that the saturated thickness of

Fig. 4. Elevation (in feet above mean sea level) of the top of the groundwater table (piezometric map) in the Alluvial Aquifer. Map from Cabrera (2006)



the Alluvium under the site ranges from 20-30 ft along the southern boundary of OU 2, 10-20 ft along the northern site boundary, with thicknesses that exceed 30 ft along the paleochannel in the top of the Denver Formation.

Slug tests performed in wells drilled into the Alluvial Aquifer (SAIC, 1990) indicate that the average groundwater flow rate in the Alluvium is 47 feet per year (ft/yr) (geometric mean flow rate 23 ft/yr) (Table 1). This means that groundwater flow across the site from the southern to northern boundary (1400 ft) takes about 22 yrs (average flow rate) or 45 yrs (geometric mean flow rate).

Table 1. Hydraulic conductivity (K), groundwater velocity and groundwater travel time In the Alluvial Aquifer under OU 2, Lowry Landfill. K values are based on the results of 20 slug tests in 9 wells.

	K (ft/day)	Hydraulic Gradient (ft/ft)	Effective Porosity (fraction)	Groundwater Velocity (ft/day)	Groundwater Velocity (ft/yr)	Travel Time* (yrs)
Min	0.1	0.01	0.3	0.0029	1.1	1330
Max	17.3	0.01	0.3	0.58	210	6.7
Average	5.3	0.01	0.3	0.18	65	22
Geometric Mean	2.6	0.01	0.3	0.085	31	45

*Measured distance from southern property boundary to northern boundary at well LFPOC10 is 1400 ft.

Based on 30 yrs of record, average precipitation at nearby Stapleton International Airport is 15.4 inches/yr (Cabrera, 2006). If 20% of this becomes groundwater recharge at OU 2, the recharge rate is 3.1 inches/yr. Assuming a recharge rate of about 3 in/yr and porosity of 0.3 for the Alluvium at the Lowry site, leads to a yearly fluctuation in the groundwater level of about 10 inches. Consistent with this estimate, seasonal water table fluctuations of the Alluvial Aquifer at the Rocky Mountain Arsenal range from about 1-3 ft (PHA, 1996). Three inches/yr of infiltration represents a relatively small contribution to the volume of underlying groundwaters, and probably a minor effect on groundwater quality in the Alluvium.

4. Chemical Composition of the Groundwater

   a. Uranium Concentrations in the Regional Alluvial Aquifer

Uranium concentrations in alluvial groundwaters in the Denver Basin are generally elevated and often exceed 70-100 μg/L. In fact the average concentration of 24 μg/L is just below the EPA drinking water standard of 30 μg/L U. The U.S. Geological Survey believes that the elevated U concentrations come from the dissolution of minerals present in the sediments, and not from man's activities. Lowry Assumption (2008) discusses these points in detail, and they will not be considered further in this report.

b. Groundwater Composition at the Site

Chemical analyses of groundwaters from 17 wells drilled into OU 2, and sampled in 2005 and 2007 are given in Table 2. These analyses were obtained from Cabrera (2006) and LTE (2007), respectively. Redox (Eh) and dissolved oxygen (DO) measurements obtained by Cabrera in 2005 are drastically lower than the values measured in 2007, and appear erroneous. Consequently, only the Eh and DO measurements reported in 2007 are tabulated and used in this study.

Comparing relative concentrations of the predominant cationic and anionic species in the groundwater, indicates that the prevalent chemical character of the groundwater is generally of the type: Ca ~ Na > Mg -- HCO3 > SO4 > Cl.

Values of specific conductance and dissolved uranium measured in 2005 and 2007 are plotted and compared in Figs. 5 and 6. The plots show that these parameters/species differed by about 2 and 3% between February 2005 and February 2007. Such small differences and the slow rate of groundwater flow (average 47 ft/yr) indicate that alluvial groundwaters under OU 2 change little in composition from year to year. This indicates that the groundwater has had sufficient time to come to chemical equilibrium with most of the minerals present in the Alluvium.

Fig. 5. Comparison of 2005 & 2007 specific conductance values, same wells

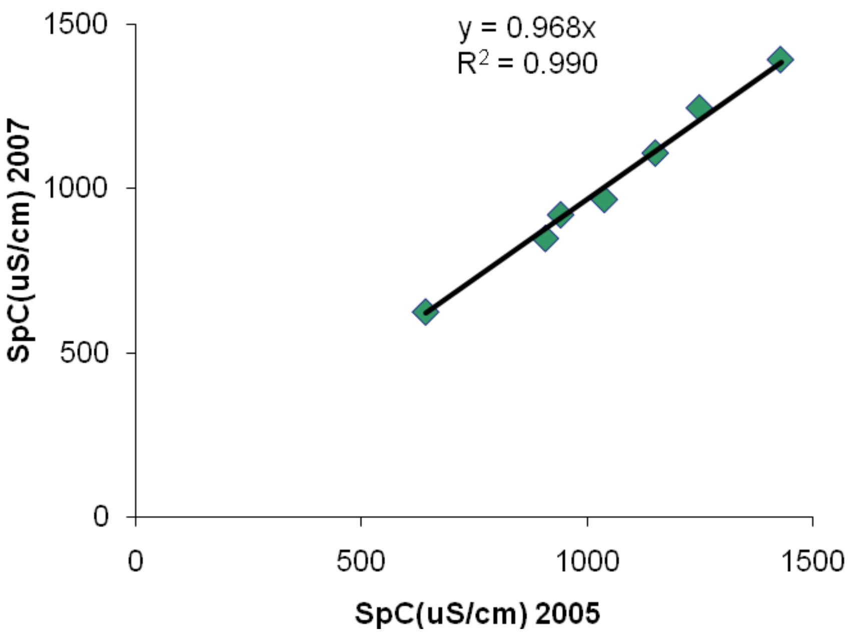


Fig. 6. Comparison of U concentrations in same wells 2005 and 2007

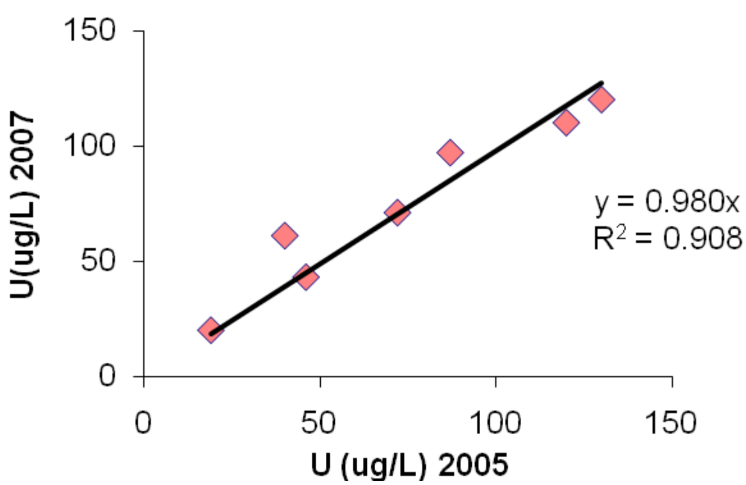


Table 2. Chemical analyses of groundwater samples collected in February 2005 and February 2007. Whenever data was available for 2007 samples, that data is listed and the data from 2005 has been ignored.

		LFPO Wells									
	Well No	01	02	03	04	06	07	08	09	10	11
T	(°C)	14.3	14.6	13.8	14	10.7	6.6	10.8	16.4	13.3	13.5
pH		7.47	7.58	8.51	7.58	7.23	7.59	6.8	7.27	6.97	7.55
DO	(mg/L)						8.16	7.46	10.5	6.05	
Eh	(mv)						233	226	181	130	136
HCO_3	(mg/L)	177	183	128	128	226	201	238	183	214	287
U	(µg/L}	79	97	26	24	32	43	120	71	110	97
SO_4	(mg/L)	120	100	58	54	400	73	89	96	79	80
Cl	(mg/L)	70	76	40	39	94	56	93	63	78	98
Ca	(mg/L)	76	84	37	39	120	68	120	82	98	110
Mg	(mg/L)	12	14	5.4	6	24	12	17	13	16	24
Na	(mg/L)	110	100	83	78	220	110	100	98	100	130
K	(mg/L)	1.8	2	0.5	1.1	4.5	1.7	1.5	2.7	1.5	3.6

Table 2. Contd.

	Well No	BG2	BG5	BG6	LZ3	LZ5	LZ10	LZ13
T	(°C)	10.6	14.7	13.6	10,1	9.4	10.4	6.2
pH		7.42	7.05	7.46	7.12	7.01	7.52	7.24
DO	(mg/L)		4.35	4.18				
Eh	(mv)		198	198				
HCO_3	(mg/L)	201	256	134	262	201	195	195
U	(µg/L}	42	61	20	130	43	150	38
SO_4	(mg/L)	500	120	52	90	420	95	74
Cl	(mg/L)	93	200	220	98	74	69	56
Ca	(mg/L)	160	160	57	140	180	100	60
Mg	(mg/L)	32	50	9.7	20	35	11	21
Na	(mg/L)	190	84	59	110	130	96	98
K	(mg/L)	2.2	9.6	1.3	1.7	2	1.2	2

A map showing uranium concentrations in the wells based on the February 2005 sampling is given in Fig. 7. Also shown is the uranium concentration for well LFPOC13 which was sampled in February, 2007 (LTE, 2007).

5. Possible Sources of Uranium in Alluvial Groundwaters

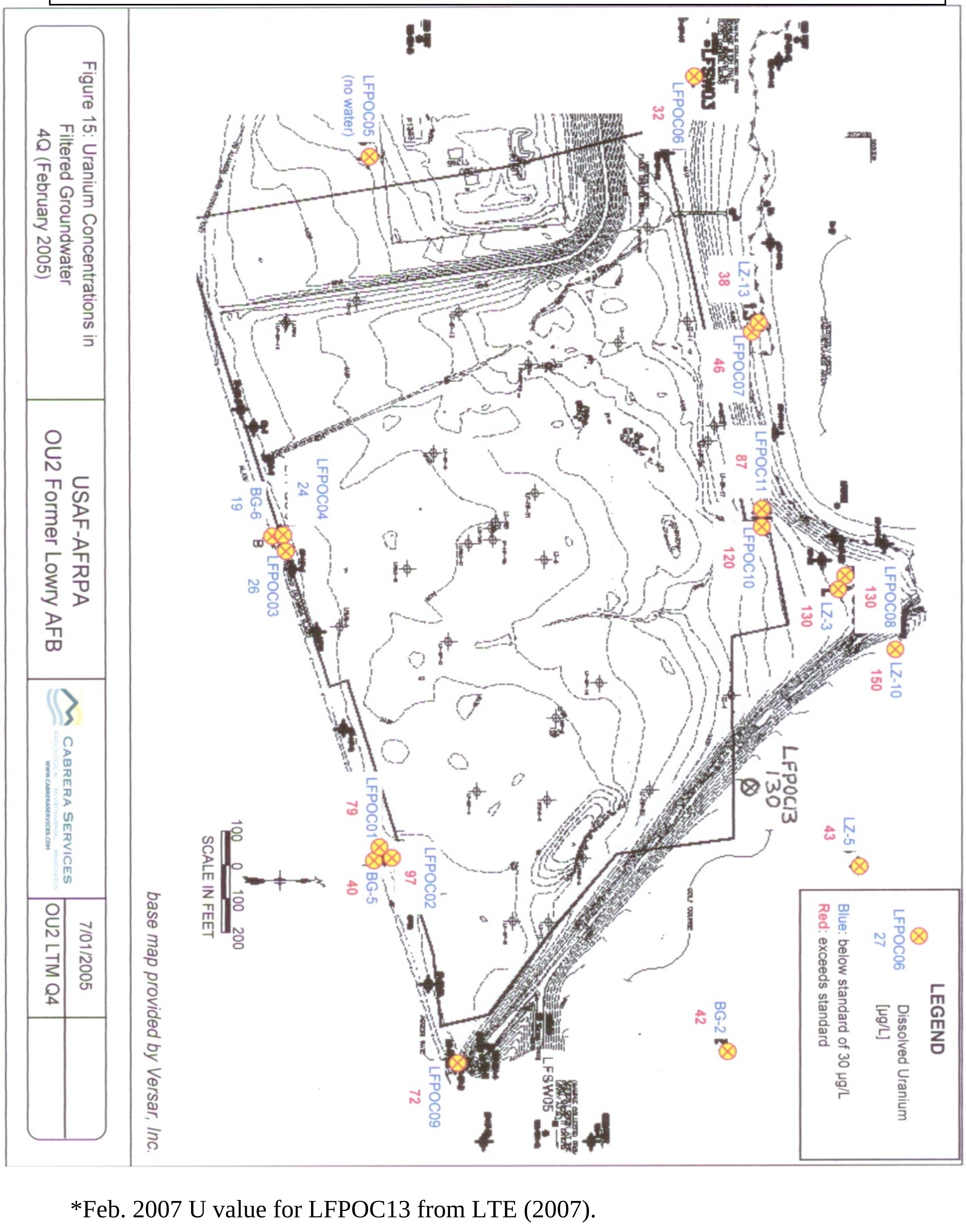
   a. Ore Deposit or Waste Ore - Mineral Saturation Calculations

Uranium ore deposits generally contain significant amounts of uranium minerals. Where such deposits are in contact with slow moving groundwaters, their uranium minerals should approach saturation with respect to the groundwater. The saturation state of groundwater with respect to a uranium (or other) mineral may be defined by the saturation index (SI) of the mineral, which is given by:

$$SI = log \frac{[IAP]}{[Ksp]}$$

(Langmuir, 1997). IAP denotes the ion activity product of the mineral which is computed from a chemical analysis of the water, and Ksp is the theoretical solubility product of the mineral in that water. When IAP = Ksp, and thus SI =0, the water is at saturation with respect to the mineral. When IAP > Ksp (so that SI is a positive number), the water is supersaturated with the mineral, and assuming the kinetics of precipitation are not a problem, the mineral should precipitate. If, however IAP < Ksp (SI values are negative), the water is undersaturated with respect to the mineral, and the mineral if present should continue to dissolve in the groundwater until equilibrium is attained. Because the SI is in log units, an SI of -1 means that the solution is undersaturated by a factor of 10, and an SI of -2 denotes undersaturation by a factor of 100 times.

Fig. 7. Topographic map of the site showing land surface elevations in feet above mean sea level, and uranium concentrations measured in wells sampled in February 2005 and February 2007 (LFPOC13 only)*. 2005 data from Cabrera (2006).



*Feb. 2007 U value for LFPOC13 from LTE (2007).

In studies of sandstone-type uranium deposits in Texas and Wyoming, Langmuir and Chatham (1980), and Chatham et al. (1981) found that when groundwaters in those deposits were in contact with uranium minerals, equilibration of the groundwater with the minerals caused the water to be at saturation (in equilibrium) with respect to them (SI values for the minerals were near zero in the ore deposits). Some uranium minerals that have been found in sandstone-type uranium deposits such as those that have been mined in Colorado, are given in Table 3.

In oxidizing environments (where measureable oxygen is present), uranium in minerals occurs in its oxidized form, as uranyl (U(VI)) species. Minerals that contain uranyl ion include the autunites, rutherfordine, schoepite, carnotite and tyuyamunite. In reducing (oxygen-free) groundwaters the water may equilibrate with minerals that contain U(IV) such as uraninite or coffinite. The groundwater analyses in Table 2 show that DO concentrations exceed 4 milligrams per liter (mg/L) in all well waters, indicating that groundwaters in the Alluvium under OU 2 are oxidizing. Thus they should not be able to equilibrate with U(IV) minerals, but might equilibrate with uranyl minerals.

Table 3. Some uranium minerals that occur in sandstone-type uranium deposits, their general formulas, and the state of uranium oxidation in them.

Mineral	Formula	Uranium Oxidation State
Schoepite	$(UO_2)_4O(OH)_6.6H_2O$	Oxidized –as U(VI)
Rutherfordine	UO_2CO_3	Oxidized –as U(VI)
Autunite	$Ca(UO_2)_2(PO_4)_2.10\text{-}12H_2O$	Oxidized –as U(VI)
K-Autunite	$K_2(UO_2)_2(PO_4)_2.10\text{-}12H_2O$	Oxidized –as U(VI)
Na-Autunite	$Na_2(UO_2)_2(PO_4)_2.10\text{-}12H_2O$	Oxidized –as U(VI)
UO_2HPO_4		Oxidized –as U(VI)
Carnotite	$K_2(UO_2)_2(VO_4)_2.3H_2O$	Oxidized –as U(VI)
Tyuyamunite	$Ca(UO_2)_2(VO_4)_2.5\text{-}8H_2O$	Oxidized –as U(VI)
Uraninite	UO_2	Reduced –as U(IV)
UO_2 amorphous	$UO_2(am)$	Reduced –as U(IV)
Coffinite	$USiO_4$	Reduced –as U(IV)

Many important uranyl minerals in Table 3 contain phosphate or vanadate ions. Cabrera (2006) analyzed 17 site well waters for phosphate in 2005, and found PO_4 concentrations as P were below detection (less than 0.2 or 0.4 mg/L) in 14 well waters, and ranged from 0.2 to 0.44 mg/L in the 3 remaining well waters. Given the general lack of information on P, based on typical phosphate concentrations in groundwater it was assumed in subsequent geochemical modeling calculations that phosphate as PO_4 = 0.1 mg/L[1].

[1] The median P concentration in surface and groundwaters is 20 µg/L or 0.020 mg/L (Langmuir, 1997). This is equivalent to a phosphate concentration as PO_4 of 61 µg/L or 0.061 mg/L.

Examination of vanadium concentrations in well waters from OU 2 indicated that detectable V values ranged from about 0.3 to 30 μg/L (SRI, 1995). These minimum and maximum values were assumed in calculations of the saturation indices of carnotite and tyuyamunite.

Saturation indices were computed using the PHREEQC geochemical model (Parkhurst and Appelo, 1999), using two different approaches to define oxidizing/reducing conditions. Based on the presence of DO > 4 mg/L and measured Eh values of the groundwaters, in the first set of runs it was assumed that all dissolved U was present as U(VI) species. The results are given in Table 4.

In the second set of SI calculations the modeling assumed that the concentrations of reduced (U(IV)) and oxidized (U(VI)) uranium species could be determined from the total dissolved uranium concentration in Table 2, taking into account the measured or estimated Eh value. When the Eh had not been measured, it was assigned a value of 237 millivolts (mv) (pe = 4.0), indicative of oxidizing conditions for the calculation of SI values. Results are shown in Table 5.

Table 4. Saturation indices (SI values) of some uranium (VI) minerals in groundwaters under OU 2, former Lowry AFB Landfill, assuming all dissolved uranium is as U(VI) species.

	(PO_4 = 0.1 mg/L) (V = 0.3 ug/L)		(PO_4 = 0.1 mg/L) (V = 30 ug/L)	
	SI	Std Deviation	SI	Std Deviation
Schoepite	-5.00	0.34	-5.00	0.34
Rutherfordine	-4.51	0.49	-4.51	0.49
K-Autunite	-9.36	0.91	-9.36	0.91
Na-Autunite	-6.47	0.68	-6.47	0.68
Autunite	-8.53	0.77	-8.53	0.77
UO_2HPO_4	-7.69	0.61	-7.69	0.61
beta-$UO_2(OH)_2$	-4.68	0.35	-4.68	0.35
Carnotite	-4.53	0.39	-2.51	0.39
Tyuyamunite	-7.50	0.76	-3.47	0.76

Table 5. Saturation indices (SI values) of some uranium (VI) minerals in groundwaters under OU 2, former Lowry AFB Landfill, with dissolved uranium speciated among U(IV) and U(VI) species using measured and assumed Eh (pe) values.

	(PO_4 = 0.1 mg/L) (V = 0.3 ug/L)		(PO_4 = 0.1 mg/L) (V = 30 ug/L)	
	SI	Standard Deviation	SI	Standard Deviation
Schoepite	-5.00	0.34	-5.00	0.34
Rutherfordine	-4.51	0.49	-4.51	0.49
K-Autunite	-9.36	0.91	-9.36	0.91
Na-Autunite	-6.47	0.68	-6.47	0.68
Autunite	-8.53	0.77	-8.53	0.77
UO_2HPO_4	-7.69	0.61	-7.69	0.61
beta-$UO_2(OH)_2$	-4.68	0.35	-4.68	0.35
Carnotite	-4.53	0.39	*-2.51*	*0.39*
Tyuyamunite	-7.50	0.76	*-3.47*	*0.76*
Uraninite	-2.55	1.58	-2.55	1.58
UO_2(am)	-8.41	1.56	-8.41	1.56

Regardless of the assumed vanadium concentration, or the approach taken to speciate the uranium (all U assumed as U(VI), or U speciated between U(IV) and U(VI) using Eh) the results shown in Tables 4 and 5 indicate that groundwaters under OU 2 are substantially undersaturated with respect to any likely uranyl (U(VI)) or uranous (U(VI)) mineral or minerals, with SI values ranging from -2.5 to -9.4, and generally less than -4.5. This substantial degree of undersaturation indicates that the elevated uranium concentrations found in some well waters under OU 2 are not the consequence of dissolving uranium in an ore deposit or waste uranium ore in the Alluvial Aquifer at OU 2, and that such an ore deposit does not exist.

According to Cabrera (2006), from available permit information, 300 pounds (lbs) of uranium ore were stored at the site, but there is no evidence that such ore was disposed of at the site. A storage site in the west central part of OU 2 was identified on a map from 1951, but has not been found during numerous investigations of the site. This location is nowhere near the wells that have high concentrations of uranium, indicating that any such storage, if it occurred, has had no effect on groundwater quality.

b. Uranium Leached from Denver Formation

Shown in Fig. 8 are uranium concentrations in well waters sampled from, in, and adjacent to OU 2 (from Fig. 7). Also drawn in the figure is the estimated location of the 5395 ft contour on the erosion surface of the Denver Formation based on the contours drawn in Fig. 1.

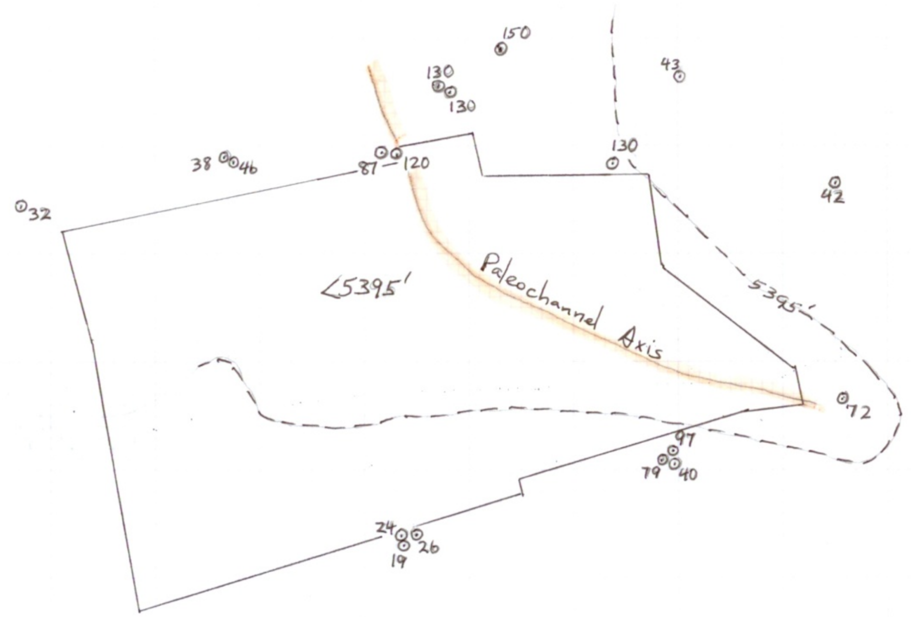


Fig. 8. Uranium concentrations in well waters in and adjacent to site OU 2. Also shown is the axis of the paleochannel eroded into the surface of the Denver Formation, and the estimated position of the 5395 ft contour eroded into the surface of

As suggested by the figure, U concentrations in the groundwater equal or exceed 100 μg/L along and to the east of the paleochannel axis. This suggests the possibility that erosion of the channel has exposed otherwise buried and reduced materials in the Denver Formation which have accumulated elevated uranium concentrations in the past, to leaching by oxygenated alluvial groundwaters. This explanation is consistent with the higher U concentrations found in groundwaters in the north-northeast part of the map where the paleochannel is deepest.

c. Uranium Leached from Phosphate Fertilizers

Examination of Fig. 7 indicates than two of the highest U concentrations in the groundwater are from wells LZ-10 (150 μg/L U) and LFPOC13 (130 μg/L U). These wells are east of Westerly Creek and within the boundary of the Mira Vista Golf Course. The Golf Course has historically spread phosphate fertilizers on their greens and fairways and irrigated the grounds. Phosphate fertilizer contains important amounts of uranium (e.g. 70-200 mg/kg; Guzman et al., 2002), which can be slowly released to underlying groundwaters (cf. Guzman et al., 2002; Zielinski et al., 2005). Guzman et al. reported that irrigation water led to infiltration of uranium to groundwater. In the vadose zone U concentrations from 3-10 mg/L (3000 to 10,000 μg/L) were measured in soil moisture. It seems possible that uranium concentrations in the alluvial aquifer east of Westerly Creek have derived at least in part from the leaching of phosphate fertilizers applied on the golf course.

Nitrogen fertilizers were also applied at the Mira Vista Golf Course. The phosphate from fertilizer is practically immobile in soils, although U from the phosphate fertilizer was presumably leached from the soil to underlying alluvial groundwaters. Similarly, nitrate from nitrogen fertilizer is highly mobile, and would be readily leached from the soil to the groundwater. As evidence for this effect, we can examine NO_3-N concentrations in the groundwater. Such data are somewhat limited, although eight wells in and adjacent to OU 2 were sampled for nitrate six times between November, 2006 and January, 2008 (LTE, Post Closure Monitoring Reports, 2007-2008). The highest nitrate-nitrogen (NO_3-N) values were found in wells LZ-13 (0.73-15 mg/L), LFPOC13 (1.4-3.0 mg/L), and LFPOC09 (6.6-7.3 mg/L). Well LZ-13 is located directly below the outfall of a surface water conveyance and the water level is very close to the surface; thus, the nitrate data is may not reflect actual groundwater conditions. LFPOC09 and LFPOC13 are at the eastern corner of the site adjacent to Westerly Creek, and east of Westerly Creek on the golf course, respectively. LFPOC13 was the only well sampled under the golf course. Its elevated nitrate values are consistent with a fertilizer source for the high levels of dissolved uranium in the well.

d. Adsorption/Desorption from Ferric Oxide Minerals in Sediments

When saturation with uranium minerals does not control U concentrations (they are well below saturation levels in a given groundwater), then they are generally 'controlled' by adsorption and desorption from mineral surfaces. The most important potential sorbent minerals for oxidized uranium (U(VI)) in the Alluvium are the ferric oxides (e.g. goethite, ferrihydrite).

Adsorption/desorption of dissolved U(VI) is controlled by several variables (cf. Hsi and Langmuir, 1981; Langmuir, 1997). These include the amount (reactive surface area) of Fe(III) oxides, pH, alkalinity and uranium concentrations. Uranium sorption is most likely to be important in the Alluvial Aquifer, where it will tend to store and release uranium back to the groundwater as appropriate changes occur in the groundwater chemistry. This process tends to buffer uranium (uranyl or U(VI) species) concentrations in individual well waters in the Alluvium at relatively constant values. In simplified terms the adsorption of dissolved (aqueous) U(VI) may be written:

$$U(VI)_{aq} + \text{Fe oxide} = U(VI)_{sorbed}\text{-Fe oxide}$$

The higher the percent of Fe oxides in the sediment (they average 1% as Fe, and are up to 3% as Fe in the Alluvium) the more uranium is adsorbed, and the lower will be its remaining dissolved concentration in the water.

$U(VI)_{aq}$ as UO_2^{2+} ion also reacts with dissolved carbonate in the groundwater forming uranyl-carbonate complexes. For example:

$$UO_2^{2+} \text{ (uranyl ion)} + 2CO_3^{2-} \text{ (carbonate ion)} = UO_2(CO_3)_2^{2-} \text{ (uranyl dicarbonate complex)}$$

Uranyl carbonate complexes are poorly adsorbed by the iron oxides. The higher the alkalinity (content) of the groundwater, at a given pH, the more uranyl carbonate complexes are formed and thus less uranyl sorption can take place. Note that HCO_3^- n the alluvial groundwaters averages 201 mg/L or $3.3x10^{-3}$ mol/L. The amount of carbonate (CO_3^{2-}) in the water increases relative to bicarbonate (HCO_3^-) as the pH increases.

Shown in Fig. 9. is the trend in uranium adsorption by goethite as a function of pH and increasing carbonate content. Total carbonate (C_T) is the sum of all carbonate species, but as a first approximation equals bicarbonate in alluvial groundwaters which have pH values generally between pH 6.8 and 7.6. The alkalinity in these waters averages 201 mg/L ($3.3x10^{-3}$ mol/L), and ranges from 128 to 289 mg/L as bicarbonate. The uranium concentration ranges from 24-150 µg/L and averages 70 µg/L. Figure 9 shows that as the alkalinity increases above about pH 6-7, uranium is desorbed from the goethite and thus increases in solution, because of increased uranyl carbonate complexing.

Uranium concentrations and pH values in alluvial groundwaters are plotted in Fig. 10. The data plot in this figure is consistent with the plot in Fig. 9, but cannot be expected to match it given the variable alkalinity of the groundwater, and variable amounts of iron oxide in the sediment versus the fixed amount in the experiments described in Fig. 9.

It is of interest to estimate how much of the uranium in the alluvial aquifer is dissolved in the pore water and how much is adsorbed on iron oxides in the Alluvium. The total uranium concentration in the experimental study described in Fig. 8 is 10^{-5} mol/L, or 2.38 mg/L. At a dissolved uranium concentration of 100 µg/L (0.1 mg/L), the amount dissolved is only about 4% of the total. In other words, 96% of the uranium is adsorbed. A similar adsorbed U percent can be expected in the Alluvium. This adsorbed U will buffer dissolved U concentrations in the groundwater, which therefore should change little from year to year.

6. Concluding Remarks

Groundwaters in the Alluvium are substantially undersaturated with respect to any likely uranium minerals, precluding the existence of a uranium ore deposit or waste uranium ore in the Alluvium at OU 2. Further, the young age and conditions in the alluvial aquifer are inappropriate for it to contain a natural uranium ore deposit. Elevated uranium concentrations in alluvial groundwaters are probably leached from the underlying Denver Formation and/or perhaps locally from phosphate fertilizers applied at the golf course east of Westerly Creek. Once in alluvial groundwaters, sorption/ desorption of uranium by iron oxides buffers and maintains its elevated concentrations in those groundwaters.

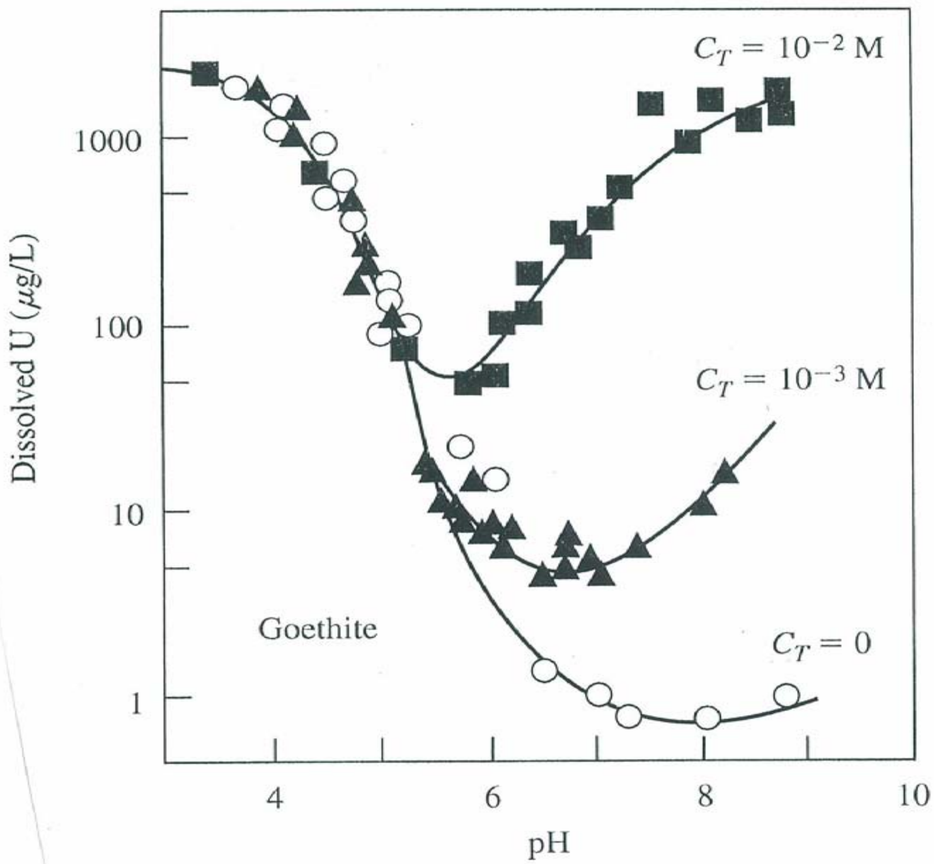
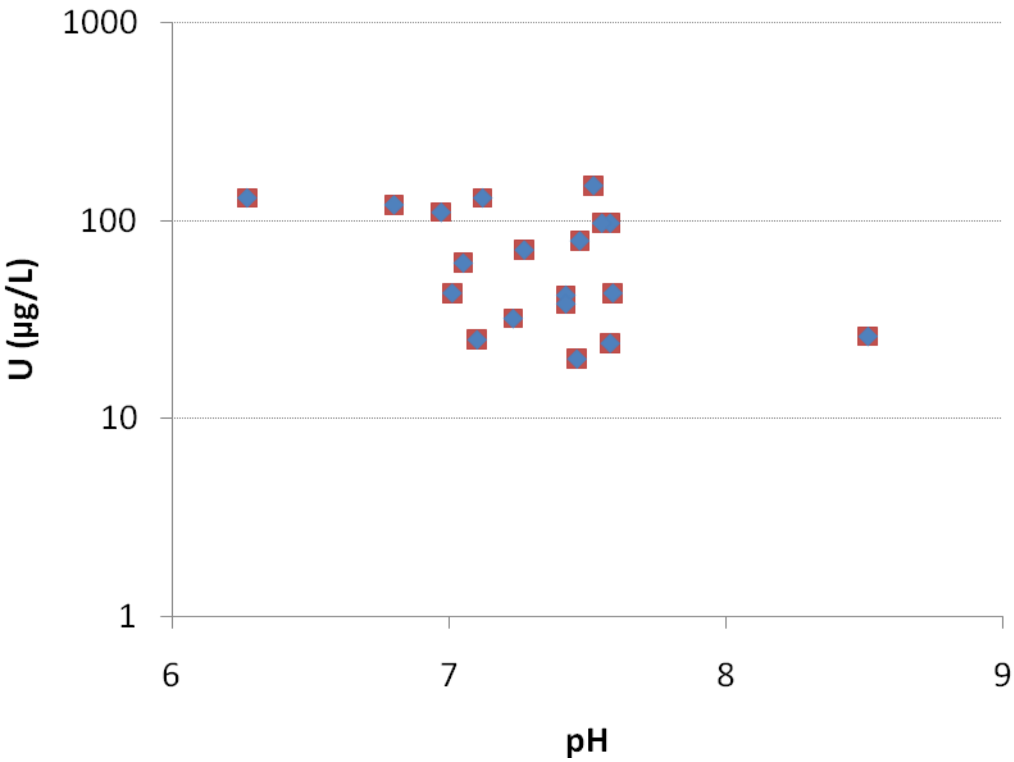


Fig. 9. The effect of changes in total carbonate (C_T) and pH on the adsorption of U(VI) onto a 1 g/L suspension of the Fe oxide mineral goethite (FeOOH) in 0.1 M $NaNO_3$ solutions as 25°C for total U = 10^{-5} M (2.38 mg/L). From Hsi and Langmuir (1985). See also Langmuir (1997).

Fig. 10. Uranium concentrations in Alluvial well waters plotted vs pH



9. References

Adler, H.H.,1963, Concepts of genesis of sandstone-type uranium deposits. Econ. Geology 58(6), 839-852.

Cabrera, 2006, Comprehensive Summary Report. Long-Term Monitoring for Radiological Parameters Operable Unit 2, Former Lowry Air Force Base, Colorado. Final Report prepared by Cabrera Services Inc., E. Hartford CT, for U.S. Air Force Real Property Agency, Denver, CO. Contract No. FA8900-04-D-9000.

Chatham, J. R., Wanty, R. B., and Langmuir, D., 1981, Groundwater prospecting for sandstone-type uranium deposits: The merits of mineral-solution equilibria versus single tracer element tracer methods. Final Report, GJO 79-360-E. Colorado School of Mines, Feb. 1981. Prepared for U.S. Dept. of Energy, Asst. Sec. for Resource Applications, Grand Junction, CO.

Guzman, E.T.R., Alberich, M.V.E., and Regil, E.O., 2002, Uranium and phosphate behavior in the vadose zone of a fertilized corn field. J. Radioanalytical & Nuclear Chem. 254(3), 509-517.

Hsi , C-K.D., and Langmuir, D., 1985, Adsorption of uranyl onto ferric oxyhydroxides: Application of the surface complexation site binding model. Geochim. et Cosmochim. Acta 49(11), 2423-32.

Langmuir, D., 1997, Aqueous Environmental Geochemistry. Prentice-Hall. Upper Saddle River, NJ. 600 pp.

Langmuir, D., and Chatham, J.R., 1980, Groundwater prospecting for sandstone-type uranium deposits: A preliminary comparison of the merits of mineral-solution equilibria, and single-element tracer methods. J. Geochemical Exploration 13, 201-219.

Lowry Assumption, LLC 2008, Evaluation of Monitoring for Radiological Parameters, Landfill Zone, OU2, Former Lowry Air Force Base, March 2008. Lowry Assumption, LLC. April 4, 2008 presentation.

LT Environmental, January 17 2007, Groundwater, Surface Water and Soil Vapor Monitoring Report. Post-Closure Monitoring, Fourth Quarter 2006, OU2 Landfill Site, Former Lowry Air Force Base, Denver, CO.

LT Environmental, April 18, 2007, Groundwater, Surface Water and Soil Vapor Monitoring Report. Post-Closure Monitoring, First Quarter 2007, OU2 Landfill Site, Former Lowry Air Force Base, Denver, CO.

LT Environmental, June 27, 2007, Groundwater, Surface Water and Soil Vapor Monitoring Report. Post-Closure Monitoring, Second Quarter 2007, OU2 Landfill Site, Former Lowry Air Force Base, Denver, CO.

LT Environmental, November 14, 2007, Groundwater, Surface Water and Soil Vapor Monitoring Report. Post-Closure Monitoring, Third Quarter 2007, OU2 Landfill Site, Former Lowry Air Force Base, Denver, CO.

LT Environmental, January 21, 2008, Groundwater, Surface Water and Soil Vapor Monitoring Report. Post-Closure Monitoring, Fourth Quarter 2007, OU2 Landfill Site, Former Lowry Air Force Base, Denver, CO.

LT Environmental, March 20, 2008, Groundwater, Surface Water and Soil Vapor Monitoring Report. Post-Closure Monitoring, First Quarter 2008, OU2 Landfill Site, Former Lowry Air Force Base, Denver, CO.

LTE, 2007, Radiological Groundwater Monitoring Report. Post-Closure Monitoring April 2007, OU2 Landfill Site, Former Lowry Air Force Base, Denver, CO. Submitted by: LT Environmental Inc., Arvada, CO. To: Ms. Sheila Gaston, Colorado Dept. of Public Health & Environment, Hazardous Materials & Waste Management Div., Denver, CO, on April 18, 2007.

Nichols, D.J., 1999, Summary of Tertiary coal resources of the Denver Basin, Colorado. Chapt. SD *in* U.S. Geol. Survey Prof. Paper 1625-A.

PHA, 1996, Public Health Assessment, Rocky Mountain Arsenal, Adams County, CO, CERCLIS NO. CO5210020769. Agency for Toxic Substances and Disease Registry, Div. of Health Assessment & Consultation, Fed. Programs Branch, Defense Facilities Assessment Section.

Phoenix, D.A., 1958, Uranium deposits under conglomeratic sandstone of the Morrison Formation, Colorado and Utah. Geol. Soc. America Bulletin 69(4), 403-417.

SAIC, 1990, Installation Restoration Program Final Remedial Investigation Report, Lowry Air Force Base, Colorado. Science Applications International Corp., McLean, VA.

SRI, 1995, Supplemental Remedial Investigation/Feasibility Study. Lowry Air Force Base, Colorado.

USGS, 2005, Ground Water Atlas of the United States. U. S. Geological Survey. http://capp.water.usgs.gov/gwa/

Voss, W.C., and Gorski, D.E., 2007, Report on the Centennial Project Weld County, Colorado. March 28, 2007. Prepared for: Powertech Uranium Corp., Vancouver, BC. http/www.powertechuranium.com/i/pdf/Centennial43-101.pdf

Zielinski, R.A., Orem, W.H., Simmons, K.R., and Bohlen, P.J., 2006, Fertilizer-derived uranium and sulfur in rangeland soil and runoff: A case study in central Florida. J. Water Air & Soil Pollution. Published online 14 July 2006.

Attachment 2
APRIL 7 PRESENTATION TO CDPHE

Evaluation of Monitoring for Radiological Parameters

Landfill Zone, OU2

Former Lowry Air Force Base

April 2008

Background

- In response to comments from CDPHE (11/20/06) on Cabrera's Final LTM for Radiological Parameters:
  - – performed two additional rounds of sampling for a full suite of radiological parameters
  - – LAC hired an expert, Dr. D. Langmuir, to evaluate the site data and to evaluate the post-closure monitoring program

Lowry Assumption, L.L.C.

Dr. Donald Langmuir

- 30 yrs of research, teaching and consulting in geology and geochemistry of radionuclides
- Professor at Pennsylvania State University and Colorado School of Mines
- Researcher for USGS (most recently re: Yucca Mtn. proposed nuclear waste repository)
- Published ~200 papers and an advanced textbook (Aqueous Environmental Geochemistry)
- BS, MS and PhD from Harvard University

Lowry Assumption, L.L.C.

Dr. Langmuir, Con't.

- Served on or chaired 20 Expert Panels, including:
  - Nuclear Regulatory Commission
  - Department of Energy
  - Lawrence Berkeley Laboratory
  - Lawrence Livermore National Laboratory
  - EPA - Radiation Advisory Committee of Science Advisory Board
  - Member, US Nuclear Waste Technical Review Board - Appointed by Presidents Reagan, Bush, & Clinton
  - Senior Advisory Scientist, Los Alamos National Laboratory

Lowry Assumption, L.L.C.

Project Overview

- Review of historical data
- Evaluation of new data
- Assessment of results
- Goal - Recommendations for post-closure monitoring program

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Lowry Assumption, L.L.C.

Project Overview

- CDPHE comments on Final Cabrera Report:
  - History of disposal
  - Site Characterization (background data and geochemistry)
  - Data quality
  - Non-uranium constituents
- LAC additional sampling and evaluation:
  - Expands discussion of history
  - Re-evaluated and concurs that Eh data reported by Cabrera may be in error
  - Expands and analyses baseline data set
  - Expands background data set (USGS data, South Platte data)
  - Results for non-uranium analytes similar to Cabrera results, below regulatory concern

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Lowry Assumption, L.L.C.

Conclusion Summary

- Elevated concentrations of uranium and gross alpha have been detected at northeast corner/east side of landfill
- Under the approved post-closure monitoring statistical analysis, Gross Alpha does not have “statistically significant” higher concentrations in downgradient wells
- Ratios demonstrate naturally occurring uranium
- Data do not demonstrate a connection to the reported burial site
- Potential explanations:
  - Natural source, consistent with other data in basin
  - Examples of other similar detections
  - Evapotranspiration concentrates U
  - High TDS in upgradient surface water recharge
  - Leaching of phosphate fertilizers
- Recommendations for post-closure monitoring
  - Gross alpha and gross beta currently in post-closure monitoring program are adequate to detect any changes in conditions

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Lowry Assumption, L.L.C.

Background

- Landfill history
  - Disposal of general refuse (1948-1979)
  - Disposal of construction rubble (1979-1989)
  - Trenches up to 15 ft deep

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Lowry Assumption, L.L.C.

Remedy

- Capped in 2004, 18 inch low permeability soil cap
- Final construction approved by CDPHE in 2006
- Undergoing post-closure monitoring (groundwater, surface, water, gas)
  - Quarterly monitoring began in November 2006
  - Cap inspections
  - Two additional quarters of data for radionuclides by LAC

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Lowry Assumption, L.L.C.

Previous Investigations / Results

- IRP records search, IRP Phase II, RI, SRI, FFS, OU5 RI
  - All studies have shown elevated U or GA in NE corner of landfill, upgradient and on the east side of Westerly Creek
  - Internal landfill GA data (OU5 Fig 5.7-17) show dispersed elevated detections upgradient, internal, east side, golf course area and at NE face, but not a clear source area
  - Previous studies all concluded that uranium was naturally occurring and other radionuclides were not of concern

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Lowry Assumption, L.L.C.

Previous Investigations / Summary

- FFS:
  - "Gross alpha and beta radionuclides were detected at all background locations and depths" (3-21).
  - "The results of the gamma spectral and tritium analyses indicated that the radionuclide activities in the landfill groundwater were low and the uranium present is naturally occurring." (3-27)
  - "The results of the FFS do not indicate a source within the Landfill Zone." (3-98)
- OU5 RI
  - "The anomalously high metals concentrations and radionuclide activities, however, are from a single surface water sample from a single sampling event, and may be a function of the sampling method and turbidity of the sample."(5.7-21)
  - "The extensive data set presented in the preceding sections indicates no major releases, past or present from the landfill into groundwater." (5.7-18)

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Lowry Assumption, L.L.C.

Information on "Burial Site" (1/2)

1951 - Original source: Real Estate Map.

1952 - Description: Real property record: "DRUM, metal, enclosing drum, metal, 35-gal. with space between filled with concrete with 4" (plus) cover of concrete. Above imbedded in ground with enclosure of 4x4 lumber topped with 3 strand barb wire to form 20' square protective fence

1958 – 1959 - AF discontinued any disposal of low level materials at bases, and began using licensed commercial sites (1992 Memo, see below)

1983 - 1987 – Records Search. – lists contents of drum to be electron tubes

1990 - Remedial Investigation - Surface geophysics conducted, sampling for gross alpha, beta, radium 226, 228, and gamma spectral analysis in groundwater and surface water.

1992 – List of Identified Waste Burial and Contaminated Sites – provides additional information regarding AF practices for disposal, allowing low level materials including electron tubes, and radium paint wastes

1993 - Basewide EBS - samples collected for gross alpha and beta to locate presumed vault.

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Investigations of "Burial Site" (2/2)

1995 - Supplemental RI - geophysics performed, surface water, sediment, soil and groundwater samples (32 samples from 2 rounds) for GA and GB. Elevated concentrations were distributed around the landfill, not directly downgradient from reported burial location or other apparent source area.

1996 - Final Facility Assessment - No visual evidence of the fenced area was found during inspection of aerial photographs.

1996 - Focused Feasibility Study - Wells sampled for GA and GB plus additional radionuclides, concluded that results did not identify any source in the landfill. Noted elevated GA and GB both up and downgradient of landfill.

1999 - Versar additional review of aerial photos and performed field reconnaissance, no surface indication found.

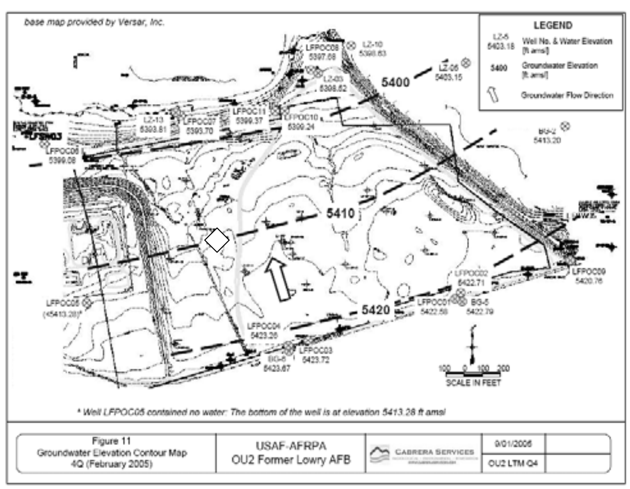
2004 – RFA reviewed over 8000 documents, records, maps, permits; no additional information on disposal in the landfill was found

2005 – Cabrera performed expanded historical review and radionuclide analysis and did not observe a source in the landfill

2007 - LAC performed additional review of aerial photos from each year from 1951-1983 (except 1969) and the reported burial site fenced area is not visible in 1951-1954 or any other year.

GW Flow Direction and Reported Burial Site

◇ Approximate location of reported burial site



Lowry Assumption, L.L.C.

RFA Permit Review

- 2005 –Extensive review of practices/permits for radiological materials performed in the RFA
  - Permits in place starting in 1959 for small quantity calibration sources, test samples, etc. Describes closeout of each permit.
  - Permit history shows one reported Low Level Radioactive disposal site (Section 4 RFA). Potentially holding items such as electron tubes, radium paints.
  - Permit for use of uranium ore (22 individual rocks 6x6x4" – 1x1x1") for a radiation source in disaster preparedness training (1982).
    - Ore was disposed as normal waste based on direction from RIC and CO Bureau of Mines.
  - Permit for dumpster containing 250-300 lbs (weight equiv to ~ 20 gallons). Dumpster processed under CDPHE supervision and ore transferred to USGS.

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Lowry Assumption, L.L.C.

Cabrera Study

- Evaluated a large number of radionuclides in groundwater, surface water and sediment
- U-234:238 tested to identify U that has undergone separation processing
- U-238:U-235 tested to identify U that has been enriched or depleted
- Total activity to total mass examined against EPA's ratios for natural uranium
- **Key Result** - Uranium found represents naturally occurring material - not processed

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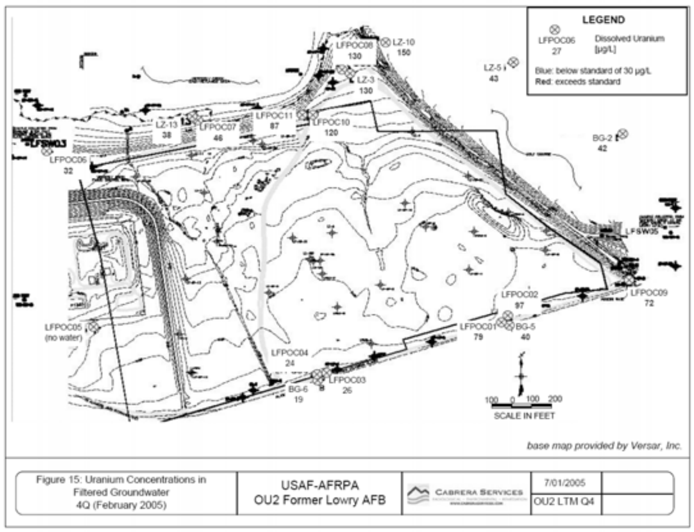
Map of Cabrera Data



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2007 Evaluation

- **Two additional wells** drilled for post-closure monitoring
- **Expanded baseline data** for GA and GB through post-closure monitoring
- **Sampling plan** - developed with CDPHE in response to comments, approved 1/11/07
- **Two additional rounds** of analysis for radionuclides and gross alpha/beta
- **Data collected by LAC** - February and April 2007
- **Dr. Langmuir** - hired in September 2007 to begin review

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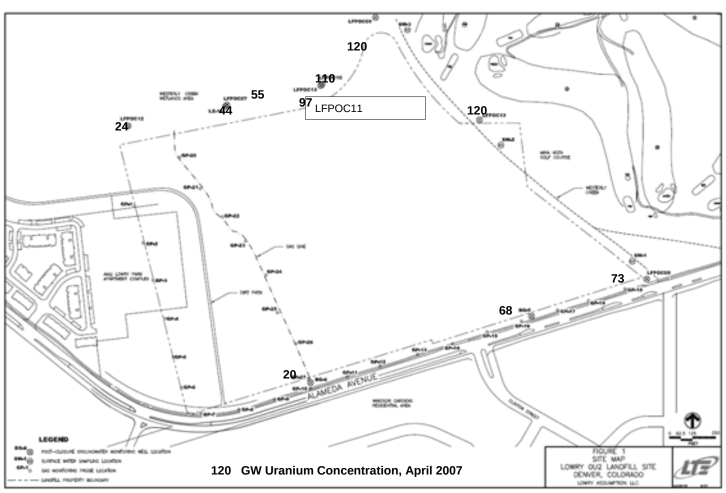
Lowry Assumption, L.L.C.

Expanded Baseline Data

- Quarterly data collected under approved post-closure monitoring program
- Includes Gross Alpha and Gross Beta
- Statistical evaluation of data is performed as specified in closure plan
- **Gross Alpha and Gross Beta concentrations downgradient are not significantly higher statistically** downgradient based on CDPHE-approved statistical method

Lowry Assumption, L.L.C.

Map of 2007 Uranium Data



Evaluation of Combined Data

- Data review by Dr. Langmuir
- Review of data for Front Range/South Platte basin
- Geochemical Evaluation (PHREEQC analysis)
- Evaluation of potential sources

Hydrological Conditions

- GW flow to north
- Depth to GW ranges from 8 - 20 ft bgs except at north end below face
- Surface water - entering from southeast, flows north along east side
- GW/SW interaction
  - Westerly Creek base at or just above GW
  - Standing water at north end is at GW elevation (OU5 and FFS X-sections)

Lowry Assumption, L.L.C.

PHREEQC Geochemical Model

- Measurable DO (>1 mg/L) indicates oxidized groundwater
- Eh data collected in Cabrera study probably in error; not consistent with more recent Eh results (measured Eh probably controlled by hydrogen peroxide/oxygen reaction. DO more meaningful than Eh to explain U geochemistry)
- Water is undersaturated with respect to any U minerals

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Lowry Assumption, L.L.C.

Potential Sources

- Natural source, consistent with other data in basin
  - Examples of other similar detections
  - Evapotranspiration concentrates U
  - High TDS in upgradient surface water recharge
- Leaching of phosphate fertilizers
  - Highest concentrations found at NE corner and on golf course

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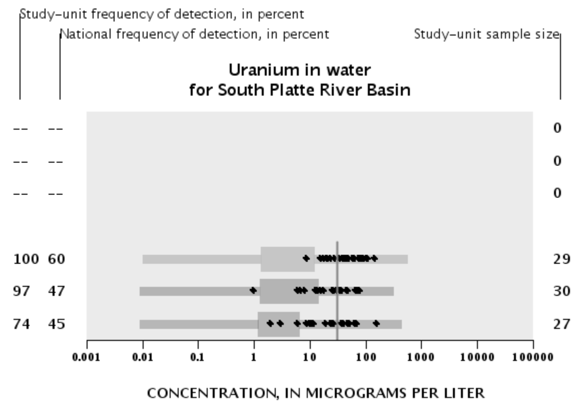
Natural Sources

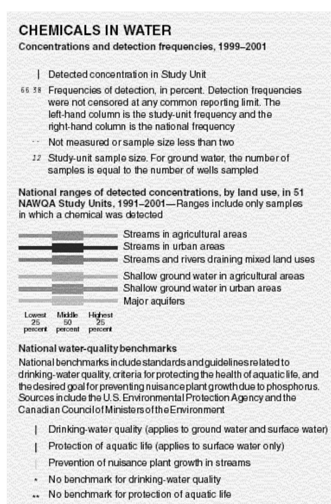
NAWQA - South Platte Valley

US Geological Survey NAWQA Box Chart (1999-2001)



- Uranium in the South Platte river Basin is higher than the national average
- Data shown here for agricultural and urban areas, and major aquifers

Box Chart Explanation



Natural Sources
Denver Basin - USGS Data

- 1995 Colorado Fact Sheet, Denver's Urban Groundwater Quality
  - *"It is likely that the source for the elevated concentrations of dissolved uranium in the alluvial ground water is from the minerals present in the sediments that make up the aquifer and not the result of effects from the urban land-use setting."*

Source: Bruce, B.W., 1995, Denver's Urban Ground-Water Quality: Nutrients, Pesticides, and Volatile Organic Compounds. Colorado Fact Sheet. U.S. Dept. of the Interior, U.S. Geol. Survey. http://co.water.usgs.gov/nawqa/splt/factsheets/FSBRUCE.html

Natural Sources
Denver Basin - USGS Data

- Data pull for uranium data from alluvial aquifers from NWIS
- Over 500 data points
- **Results: >100 ug/L** at wells in shallow/alluvial aquifers Denver, Arapahoe, Douglas, Adams, Morgan, and Elbert counties
- Maximum detected – **213 ug/l**

Lowry Assumption, L.L.C.

Natural Sources

Denver Basin – Pashke Study

- Data will be published by USGS April 2008
- Review of water quality in Denver Basin aquifers
- Author: S. Paschke
- Verbal results – elevated uranium documented in basin
  - Shallow water table wells, Upper Denver Formation, Lone Tree, Highlands Ranch, Aurora
    - max 94 ug/l
  - Alluvial aquifer near DIA, agricultural use (wheat farming), max. U = 146 µg/L in well ADLUS 12, Adams Co., Section 26, Twp. 3S, Range 64W.
    - max 146 ug/l

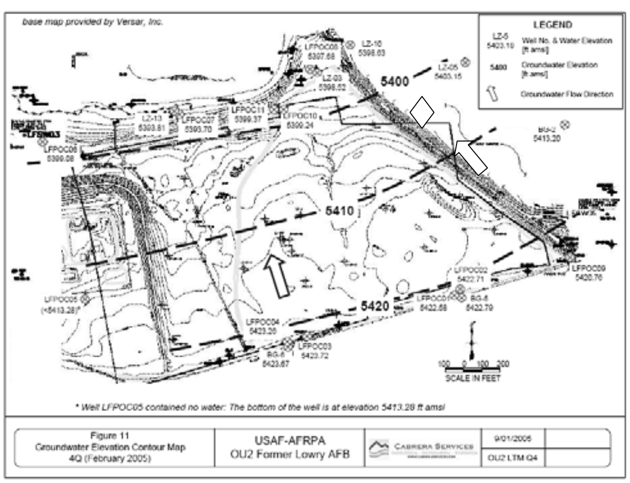
Lowry Assumption, L.L.C.

Natural Sources

Local Example - Well LFPOC13

Area east of Westerly Creek: No disposal noted in extensive aerial photo review.

Well is not downgradient of documented disposal area.



Lowry Assumption, L.L.C.

Well LFPOC13

- Drilled for post-closure monitoring 2006
- Shown as downgradient in LTE samples
- North of triangle of possible landfill area east of Westerly Creek, on golf course
- Further review of aerial photos, and excavation of area for installation of cap did not show any disposal activity in that area
- Concentrations in that well equivalent to highest concentrations in NE corner not downgradient
- Well is more probably influenced by fertilizer and natural sources
- Also, high turbidity in July sample caused resampling; after well redevelopment parameters returned to normal level

- Data from this well document
  – relationship of GA (and by extension - U) to turbidity and matrix
  – Elevated detections in area not downgradient of disposal area

Lowry Assumption, L.L.C.

Natural Sources

Nebraska Study

- Consistent pattern of high uranium concentrations in Platte River bottomlands
- Correlates well with high TDS (correlation also shown in SW06 data and recent LAC well resample)
- Highest Uranium in shallow wells downgradient from irrigated fields
- Concentrations >100 ug/L

Source: RF Spalding and CN Loope, Uranium Concentrations in Groundwater, Central Platte Region, Nebraska, 1978-1983

Natural Sources

Upgradient waters of Westerly Creek

- Surface water is chief source of recharge to the aquifer
- Drainage area is urban (draining an area of SE Aurora starting near I-225 and Yale)
- TDS is high in Westerly Creek, max ~1400 uS/cm (USGS, 1991-1992)
- TDS in interior and upgradient landfill groundwater samples ranged from 460 to 1400 uS/cm (OU5 RI Table 5.7-6)
- Variable turbidity in Westerly Creek at OU2 post-closure monitoring sample locations

  (max 62 NTU Feb '07, SW-2)

Phosphate Fertilizers from Mira Vista

- High concentrations of Uranium (and gross alpha have been found on the east side of Westerly Creek)
  - OU5 RI, OU2 post-closure
- Golf course was built in 1970 – operating for almost 40 years.
- Phosphate fertilizers reportedly contain Uranium (70-300 mg/kg) – Scotts fact sheet (Cabrera, App. F) reports 140 pCI/g (**412 mg/kg**)
- Guzman (2002) indicates that vadose zone water in fertilized areas can contain up to **12 mg/L** U in areas where fertilizer U concentration was **<200 mg/kg**
- Runoff to Westerly Creek and loss of SW to GW can contribute to high concentrations at east and north end of site.
- Golf course has confirmed that they apply phosphate fertilizer

(Guzman E.T.R., Esteller Alberich M.V., and Regil, E.O., 2002, Uranium and phosphate behavior in the vadose zone of a fertilized corn field. J. Radioanalytical and Nuclear Chem. 254(3), 509-517.)

Lowry Assumption, L.L.C.

Evapotranspiration

- Uranium tends to concentrate when recharge is subject to evapotranspiration (Langmuir, 1978)
- Paschke and Spalding studies report similar findings
- Standing water in seep at north end has always had higher concentrations than upgradient water - may reflect this process

Source: Langmuir, D., 1978, Uranium solution-mineral equilibria at low temperatures with applications to sedimentary ore deposits: Geochim. et Cosmochim. Acta, v. 42, p. 547-569. Langmuir, D., 1979, Author's reply: Geochim. et Cosmochim. Acta, v. 43, p. 1991.

Lowry Assumption, L.L.C.

Summary

- Additional collection and review of data were performed in response to CDPHE comments
- Additional post-closure monitoring data show that increase in GA concentrations downgradient are not statistically significant
- USGS and other data sources document similar uranium concentrations throughout area due to geology
- Other potential sources include phosphate fertilizers on the landfill and high TDS recharge
- Current monitoring of GA and GB are adequate to detect any potential release from the landfill